

RESISTANCE OF CRACKED CONCRETE HEALED BY MEANS OF POLYURETHANE AGAINST CHLORIDE PENETRATION.

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ABSTRACT

A lot of damage is reported for constructions in marine environments. Marine environments are very aggressive, because of the high chloride concentration in sea water. Chlorides affect durability by initiating corrosion of the reinforcement steel. When cracks appear in the concrete structures, chlorides will penetrate faster and will initiate corrosion. A possible solution is self-healing concrete. Self-healing concrete has the ability to recover without external intervention. From the literature concerning self-healing concrete, it is clear that research focuses on the general concept, the mechanical properties and water permeability. Based on the water permeability it is concluded whether harmful substances will penetrate. Specific data on degradation of self-healing concrete in aggressive environments are not available. Nevertheless, these data are important to ensure a good estimation of the service life extension.

In this research, the effect of the healed cracks on the resistance against chlorides was investigated for two concrete types, namely ordinary Portland cement concrete and blast-furnace slag concrete with 50 % cement replacement. Non-steady state migration tests, based on NT Build 492, were performed with uncracked, cracked and healed concrete. In our previous research, autonomous crack healing was obtained by encapsulating polyurethane healing agents. To release the healing agents, realistic cracks were formed by means of a controlled splitting test. In the current work, as a first step, cracks (notches) were manually healed with a two-component healing agent based on polyurethane. These cracks (notches) were formed by means of steel plates with a width of 0.1 and 0.3 mm. The migration tests were performed at constant setup parameters, namely 30 V and 8h. The chloride penetration front was visualized by means of the colorimetric method. By comparing the penetration depths, it seemed that concrete with a healed crack of 0.1 mm can fully regain its resistance against chloride penetration.

1. INTRODUCTION

A lot of damage is reported for constructions in marine environments since these environments are very aggressive, due to the presence of chlorides. A commonly used material for such structures is reinforced concrete. However, chlorides affect the durability of concrete by initiating corrosion of the reinforcement steel. Besides, cracks will facilitate chloride penetration. So, it is important to heal cracks. Since constructions in marine environments mostly have an high economical impact, fast repair of the cracks is desirable. However, repair costs are large and in some cases repair is impossible due to inaccessibility. A possible solution is self-healing concrete. Nevertheless, research on self-healing concrete mainly focuses on the general

concept, the mechanical properties and water permeability. Specific data on degradation of self-healing concrete in aggressive environments are not available. In this paper, the chloride resistance of manually healed concrete is investigated.

2. MATERIALS

Two different concrete mixtures were prepared: one Ordinary Portland Cement (OPC) mixture and one Blast-Furnace Slag (BFS) mixture where the cement replacement level amounts to 50 % (S50).

A two-component polyurethane-based healing agent was used. The first component was a prepolymer of polyurethane which starts foaming in moist surroundings; the second was an accelerator shortening the reaction time. The two components were mixed and injected into the cracks, 24 h before testing, by means of a syringe.

3. METHODS

A non-destructive method was used to generate cracks in concrete conform the method described by Audenaert et al. [1] and Song [2]. They established a notch method to produce an artificial crack in concrete by means of thin steel plates introduced into the fresh specimen. The specimen were cylindrical with a diameter of 100 mm and a height of 50 mm. Varied crack parameters such as crack width, depth and length were obtained by choosing varied sizes of sheets to insert into the concrete. The thin plates used in this research have a preset width of 0.1 mm and 0.3 mm. The crack depth was kept constant at 15 mm for crack widths of 0.1 mm, and at 20 mm for crack widths of 0.3 mm. The crack length was 60 mm.

The resistance to chloride penetration was evaluated experimentally, by means of the rapid chloride migration test as described in NT Build 492 [3]. This method was slightly adopted in order to be able to compare the chloride penetration depths of the different test series. Per concrete mixture, 5 series with at least 6 replicates were tested, namely uncracked, cracked 0.1 mm, cracked 0.3 mm, healed 0.1 mm and healed 0.3 mm. According to the method described in NT Build 492, the applied voltage during the test differs for every measurement, since the penetration depth should be smaller than the specimen height. Because of this, it was not possible to compare the colour change boundaries. Therefore, tests were performed at a constant voltage of 30 V and a constant duration of 8 hours. Afterwards, the chloride penetration was measured by means of the colorimetric method, more specifically by spraying 0.1 M AgNO₃ on both halves of the split specimen.

4. RESULTS

The results show a big difference for the chloride penetration measured at the crack tip of a 0.1 mm crack and a 0.3 mm crack. The wider the crack, the higher the penetration depth measured from the crack tip onwards. Besides, the penetration depth at the crack tips is higher than the penetration depth measured from the exposed surface. In Fig. 1 this relative increase is shown, with the penetration depth at the surface (= crack width 0 mm) as a reference. The increase in penetration depth at the tip of a 0.3 mm crack compared to the penetration from the surface amounts to 30 % and 36 % for OPC and S50 respectively (see Fig. 1).

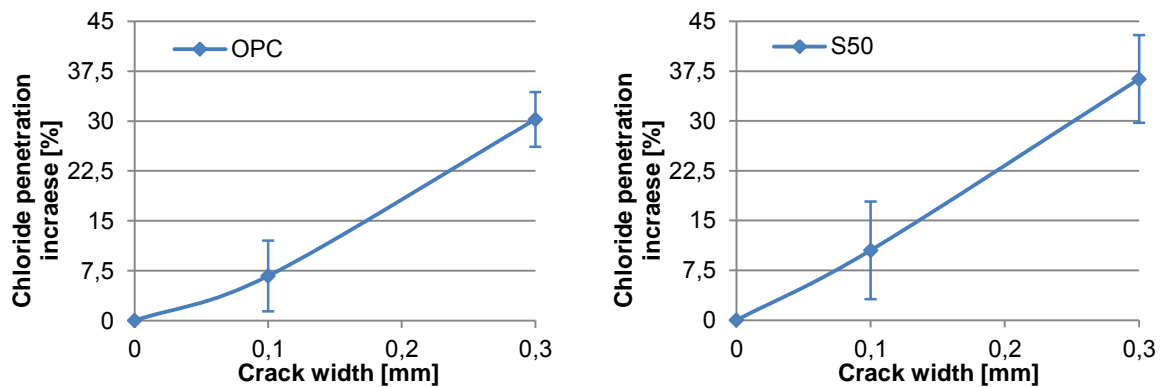


Figure 1: Chloride penetration increase in function of the crack width, for OPC and S50.

It is important to take notice of the fact that chloride penetration from crack tips is higher than from the concrete surface. Considering this, it is important to heal the cracks as quickly as possible.

In this research, the efficiency of polyurethane as a healing agent for self-healing concrete is tested preliminary by means of manual healing of the cracks.

In order to evaluate the healing effect with regard to the resistance against chloride penetration, four healing categories are defined, see Fig. 2: (1) Totally healed (no Cl^- -penetration around the crack), (2) Partially healed (a) (Cl^- -penetration perpendicular to the crack + no Cl^- -penetration at the crack tip), (3) Partially healed (b) (Cl^- -penetration perpendicular to the crack + Cl^- -penetration at the crack tip (< from the surface)) and (4) No effect.

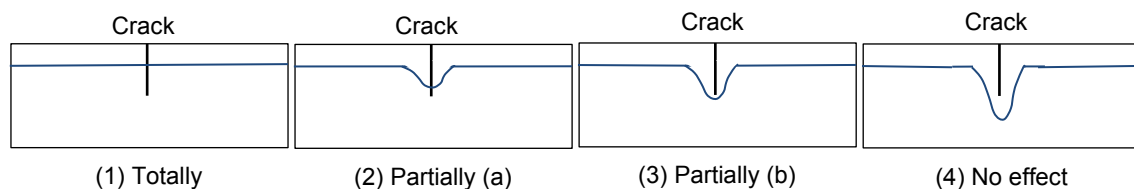


Figure 2: Visual indication of the four categories to evaluate healing based on the chloride penetration depth around the crack.

Table 1 gives an overview of the regained resistance against chloride penetration due to manual healing by means of polyurethane injection. The percentages represent the part of the healed samples belonging to the specific category. To class them, chloride penetration depths were measured and compared.

Table 1: Efficiency of manual crack healing with regard to chloride penetration.

Healing category	OPC		S50	
	0.1 mm	0.3 mm	0.1 mm	0.3 mm
(1) Totally	67 %	34 %	33 %	-
(2) Partially (a)	16 %	33 %	50 %	67 %
(3) Partially (b)	17 %	33 %	17 %	33 %
(4) No effect	-	-	-	-

According to these results, it seems that cracks with width 0.1 mm and depth 15 mm can regain almost full resistance against chloride penetration (categories 1 and 2) in 83 % of the cases. Besides, cracks with width 0.3 mm and depth 20 mm can be healed almost totally in 67 % of the cases. These findings are independent of the concrete mixture. For all samples some positive effect due to the presence of PU in the cracks was measured.

5. CONCLUSIONS

Chloride penetration at the crack tip increases in function of the crack width when the crack width is in the range of 0 mm (= penetration from the surface) until 0.3 mm. A possible solution to repair the cracked concrete is self-healing concrete. Manual healing by means of polyurethane injection shows good results. For cracked concrete with a crack width of 0.1 mm, regardless the composition, 83 % of the samples regained almost full resistance against chloride penetration. In the case that cracks have a width of 0.3 mm, 67 % of the samples regained almost full resistance.

These findings allow for further investigations concerning the resistance against chloride penetration of autonomously healed concrete, with PU as a healing agent. Autonomous crack healing will be obtained by encapsulating the healing agents. To release the healing agents, realistic cracks will be formed by means of a controlled splitting test. After cracking, the specimen will be subjected to a natural diffusion test.

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